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IMAGE PROCESSING APPARATUS AND METHOD  
AND STORING MEDIUM

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BACKGROUND OF THE INVENTION

5 Field of the Invention

The invention relates to image processing apparatus and method for efficiently compressing an image and to a storing medium in which such a method has been stored.

10 Related Background Art

In recent years, computers and networks have remarkably been developed and various information such as character data, image data, audio data, and the like are handled in a computer and in a network.

15 With respect to the image data and audio data, data of a relatively large data amount is often handled. Therefore, a process to reduce the data amount by compressing the image data and audio data has been performed hitherto.

20 For example, by compressing the image data, a large quantity of image information can be transmitted through a network at a high speed.

According to the above image compressing technique, a system (generally called a JPEG) for  
25 compressing a multivalue still image in the ITU-T Recommendation T.81 is known and a system (generally called a JBIG) for compressing a binary still image in

the ITU-T Recommendation T.82 is known.

The JPEG system is suitable for compression of a natural image such as a photograph. The JBIG system is suitable for compression of a binary image such as a black and white character.

According to the conventional JPEG system and JBIG system, all images of multivalued images (photograph or the like) and binary images (character image, diagram image, or the like) cannot be efficiently compressed without deteriorating a picture quality.

To solve the above problem, a method of separating a multivalued image portion and a binary image portion in one picture plane and compressing them by different compressing systems is also known.

The JPEG system is suitable for encoding in a case where natures of images locally differ. By properly switching an encoding system every area in each block, an efficient encoding can be executed while suppressing a deterioration of the picture quality. According to the above system, after multivalued image data was converted into a frequency component every block, by entropy encoding the frequency component, even if the natures of the images locally differ, the encoding according to each block can be executed.

On the other hand, the JBIG system does not execute the encoding on a block unit basis.

However, the system for compressing the multivalued

image and binary image as mentioned above does not satisfy all of the requirements of the user yet.

Therefore, a new image compressing system is proposed to further improve a picture quality, a processing  
5 speed, or an encoding efficiency.

#### SUMMARY OF THE INVENTION

The invention is made in consideration of the above conventional systems and it is a main object of  
10 the invention to provide a new system which can efficiently compress and can keep a high picture quality for any one of a multivalue image and a binary image.

Particularly, another object of the invention is  
15 to provide an encoding system of a high compression ratio in an encoding system for encoding an image every block.

To accomplish the above objects, according to one preferred embodiment of the invention, there is  
20 provided an image processing apparatus comprising:

first converting means for generating conversion coefficients of M values by converting input image data by a first system;

second converting means for generating conversion  
25 coefficients of N values ( $M > N$ ) by converting the input image data by a second system;

input means for selectively inputting the

conversion coefficients of M values or the conversion coefficients of N values; and

output means for outputting first information indicating a position where a significant conversion coefficient exists in a block constructed by either  
5 ones of the conversion coefficients inputted by the input means and second information indicating the significant conversion coefficient.

According to the invention, still another object  
10 of the invention is to efficiently entropy encoding block division information which is generated by a block division processing as an element technique of the new image encoding system.

To accomplish the above object, according to one  
15 preferred embodiment of the invention, there is provided an image processing apparatus comprising:

output means for outputting division information indicating whether each of a plurality of blocks including an encoding subject block has further been  
20 divided into a plurality of blocks or not; and

entropy encoding means for entropy encoding the division information corresponding to the encoding subject block on the basis of a presumption probability according to a division situation of a neighboring  
25 block of the encoding subject block.

The above and other objects and features of the present invention will become apparent from the

following detailed description and the appended claims with reference to the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

5           Fig. 1 is a whole circuit diagram of an image processing apparatus on the encoding side;

          Fig. 2 is a diagram for explaining a block dividing method of a block division unit 7;

          Fig. 3 is an outline explanatory diagram of a  
10       discrimination unit 1;

          Figs. 4A and 4B are outline explanatory diagrams of a discrete wavelet conversion unit 2;

          Figs. 5A, 5B, 5C, 5D and 5E are outline explanatory diagrams of an area dividing unit 4;

15           Figs. 6A and 6B are outline explanatory diagrams of a prediction conversion unit 3;

          Figs. 7A, 7B, 7C, 7D, 7E and 7F are diagrams showing a data format of encoding data;

          Fig. 8 is a whole circuit diagram of an image  
20       processing apparatus on the decoding side;

          Figs. 9A, 9B, 9C, 9D, 9E and 9F are diagrams showing a state of an image decoding on the decoding side;

          Fig. 10 is an explanatory diagram of progressive  
25       encoding and decoding of a multivalue image;

          Figs. 11A, 11B and 11C are explanatory diagrams of a progressive encoding of a binary image;

Figs. 12A, 12B, 12C and 12D are explanatory diagrams of a progressive decoding of a binary image;

Fig. 13 is a block diagram according to the third embodiment;

5 Fig. 14 is a diagram showing a flow of processes of a block dividing circuit 103;

Figs. 15A and 15B are diagrams showing an example of a subject block and its dividing state;

10 Fig. 16 is a diagram showing a bit string for an example of the subject block shown in Figs. 15A and 15B;

Fig. 17 is a diagram showing a block diagram in the fourth embodiment according to the invention;

15 Figs. 18A, 18B and 18C are outline diagrams of a wavelet conversion by a discrete wavelet conversion circuit 503;

Fig. 19 is a diagram showing a flow for processes of a block dividing circuit 505; and

20 Fig. 20 is a diagram showing a state where a block is further divided by the block dividing circuit 505.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

25 Fig. 1 is a schematic diagram of an image processing apparatus which is used in the first embodiment of the invention.

A flow of processes of each unit will be first simply explained.

In the diagram, image data which is inputted from an input unit in the diagram is multivalued image data having a predetermined number of bits per pixel.

5 In the embodiment, it is assumed that not only image data showing a photograph, a picture, or the like suitable for multivalued expression but also image data showing characters, diagram, or the like to be inherently expressed by a binary value is included in the multivalued image data having a depth of 8 bits per  
10 pixel.

In the embodiment, therefore, to efficiently encode image data showing an image in which those images mixedly exist, the former image is encoded as multivalued image data and the latter image is encoded  
15 as binary image data, thereby improving an encoding efficiency.

Subsequently, the inputted multivalued image data is supplied to a block division unit 7. The block division unit 7 divides the multivalued image data into  
20 multivalued image data corresponding to a block of a predetermined size shown in Fig. 2, for example, a size of  $H_b$  pixels in the vertical direction and  $W_b$  pixels in the lateral direction and sequentially outputs the divided multivalued image data on a block unit basis.

25 The outputted multivalued image data is inputted to a discrimination unit 1 in Fig. 1. The discrimination unit 1 detects the number of gradations which one pixel

has, thereby discriminating whether the multivalued image data indicates a binary image or a multivalued image. The image data discriminated by the discrimination unit 1 is also inputted to a switching unit 6.

On the basis of a discrimination result of the discrimination unit 1, the multivalued image data inputted to the switching unit 6 is outputted to a prediction conversion unit 3 if it is the multivalued image data to be expressed as a binary image and is outputted to a discrete wavelet conversion unit 2 if it is the multivalued image data to be expressed as a multivalued image. That is, a flowing direction of the multivalued image data of the switching unit 6 is switched on the basis of the discrimination result of the discrimination unit 1.

Predetermined converting processes are performed to the multivalued image data inputted to the discrete wavelet conversion unit 2 or prediction conversion unit 3. Each of the converting processes will be described hereinlater.

Conversion coefficients after they were converted by the conversion units are inputted to an area dividing unit 4. The discrimination result for each block by the discrimination unit 1 is also inputted to the area dividing unit 4.

In the area dividing unit 4, the conversion



coefficients which are inputted are compared with a predetermined threshold value. On the basis of comparison results, the conversion coefficients are further sequentially divided into small areas. A  
5 dividing process will be also explained hereinlater.

The area dividing unit 4 outputs division information indicative of a result of the dividing process of the block and the actual values and positive and negative signs of the conversion coefficients as  
10 bit data. The division information and the bit data are inputted to an entropy encoding unit 5 at the post stage.

The entropy encoding unit 5 entropy encodes the inputted bit data and outputs final encoded data.

15 The detailed operation of each block will now be described.

The block division unit 7 divides the inputted multivalue image data into blocks of a predetermined size and sequentially outputs the multivalue image data  
20 on a divided block unit basis.

It is now assumed that the multivalue image data divided into rectangular areas of a size of  $H_b$  pixels in the vertical direction and  $W_b$  pixels in the lateral direction as shown in Fig. 2 is outputted.

25 The discrimination unit 1 checks each bit of the inputted multivalue image data and discriminates whether the multivalue image data should be expressed

as a binary image (character, diagram, or the like) or a multivalued image (natural image such as photograph, picture, or the like).

Fig. 3 is a conceptual diagram showing the operation of the discrimination unit 1. The inputted image data is compared by a comparison unit 1010 and a comparison result is inputted to a counter array 1020.

Each reference value of the comparison unit 1010 corresponds to a pixel value of the multivalued image data which is inputted and its number  $L$  is set to be equal to the maximum level number (for example, 256) which can be presumed for the multivalued image data.

The comparison unit 1010 generates "1" when the result of the inputted image data is equal to each reference value and the result becomes an input to a corresponding counter of the counter array 1020. On the other hand, the image data inputted to the comparison unit 1010 is counted every pixel. At a time point when all of the pixels in the relevant block are compared, the contents of the counter array 1020 are outputted to a discrimination unit 1030 and the contents of the counter array 1020 are reset. The discrimination unit 1030 scans the contents of each counter  $C(i)$  and counts the number  $N_c$  of counters of

$$C(i) \neq 0 \quad (i = 0, \dots, L-1) \quad (1)$$

When

$$N_c = 2 \quad (2)$$

it is determined that the image data should be expressed as a binary image. When

$$N_c > 2 \quad (3)$$

it is decided that the image data should be expressed  
5 as a multivalued image.

A discrimination result is outputted to the switching unit 6 and area dividing unit 4.

On the basis of the discrimination result inputted from the discrimination unit 1, if the multivalued image  
10 data which is inputted should be expressed as a multivalued image, the switching unit 6 switches so as to output it to the discrete wavelet conversion unit 2. If the multivalued image data which is inputted should be expressed as a binary image, the switching unit 6  
15 switches so as to output it to the prediction conversion unit 3.

Encoding process as a multivalued image

Subsequently, a case where the multivalued image data which is inputted should be expressed as a  
20 multivalued image, namely, it should be processed as multivalued image data as it is (case where the discrete wavelet conversion unit 2 is made operative) will be described.

The discrete wavelet conversion unit 2 performs a  
25 discrete wavelet conversion to the inputted multivalued image data and divides it into a predetermined number of frequency bands (hereinafter, referred to as

subbands).

Fig. 4A shows a schematic diagram to execute the discrete wavelet conversion. Fig. 4B shows a conceptual diagram of subbands which are generated by the converting process.

In Fig. 4A, multivalue image data  $x$  which is inputted passes either a low pass filter  $H_0$  or a high pass filter  $H_1$  with respect to each of the horizontal and vertical directions as shown in the diagram. By performing a sub-sampling each time the data  $x$  passes the filter, the data is divided into a plurality of frequency bands.

Fig. 4B shows a processing result that is obtained by performing conversions of three stages shown in Fig. 4A to the multivalue image data corresponding to the  $W_b$  pixels in the lateral direction and the  $H_b$  pixels in the vertical direction.

In the embodiment, a size of block shown in Fig. 4B corresponds to a size ( $W_b \times H_b$ ) of the image divided into blocks by the block division unit 7.

It is assumed that each filter which is used in the embodiment is a reversible filter such that data can be perfectly reproduced at the time of image decoding.

For example, a result  $r$  obtained by performing filtering process by the low pass filter  $H_0$  and a sub-sampling to the multivalue image data  $x$  is expressed by

the following relational equation (4). A result  $d$  obtained by performing a filtering process by the high pass filter  $H1$  and a sub-sampling to the multivalue image data  $x$  is expressed by the following relational equation (5).

$$r(n) = \langle\langle (x(2n) + x(2n+1))/2 \rangle\rangle \quad (4)$$

$$d(n) = x(2n+2) - x(2n+3) + \langle\langle (-r(n) + r(n+2) + 2)/4 \rangle\rangle \quad (5)$$

where,  $\langle\langle X \rangle\rangle$ : the maximum integer which does not exceed  $X$

The discrete wavelet conversion unit 2 sequentially repeats the filtering process and the sub-sampling in the horizontal and vertical directions as shown in Fig. 4A as mentioned above and sequentially divides each block image which is inputted to a plurality of subbands.

Fig. 4B shows a name of each subband obtained by Fig. 4A and a spatial positional relation. In each subband, a conversion coefficient (frequency component) corresponding thereto is included. The conversion coefficients which are derived by the discrete wavelet conversion unit 2 are outputted to the area dividing unit 4 at the post stage on a subband unit basis.

In the embodiment, a subband of  $LL$  is first outputted, subbands of  $HL3$ ,  $LH3$ , and  $HH3$  are outputted, subbands of  $LH2$ ,  $HL2$ , and  $HH2$  are outputted, and subbands of  $LH1$ ,  $HL1$ , and  $HH1$  are subsequently

outputted. By outputting the subbands as mentioned above, the frequency components can be sequentially decoded from the low frequency component (LL) on the decoding side and an outline of the image can be early  
5 recognized.

In the area dividing unit 4 for inputting the conversion coefficients (multivalues) from the discrete wavelet conversion unit 2, only the coefficients having values within a certain predetermined range (in case of  
10 expressing the conversion coefficients of multivalues by a bit plane, coefficients existing in a bit plane in which the maximum significant coefficient bit indicates a value within a predetermined range (which is equal to or larger than  $n_{\max}$ , which will be explained  
15 hereinlater)) are extracted from the conversion coefficients and the information of each of the extracted coefficients is outputted as a bit data string.

Figs. 5A to 5E show a conceptual diagram for  
20 explaining the operation of the area dividing unit 4.

For the subbands which are sequentially inputted, the area dividing unit 4 converts the conversion coefficients in each subband into a bit data string in accordance with a procedure shown in a flowchart of  
25 Fig. 5E. Explanation will now be made with reference to the flowchart.

First, although sizes of subbands which are

inputted are not always the same size as shown in Fig. 4B, the inputted subbands themselves are defined as a subject block T as shown in Fig. 5A.

5 A maximum value  $c_{\max}$  for all of the conversion coefficients  $c_{ij}$  in the subject block T is subsequently obtained. Further,  $n_{\max}$  is obtained as follows and is set to an initial value of a subject bit plane number  $n$ .

$$n_{\max} = \log_2(|c_{\max}|) \quad (6)$$

10 In step S500, a threshold value  $Th$  regarding the subject block T is obtained by the following equation (7) by using the value of the number  $n$  which has been set at present.

$$Th = 2^n \quad (7)$$

15 In step S501, when the present number  $n$  is less than a predetermined minimum bit plane number  $n_{\min}$ , the process of the subject block T is finished.

In steps S502, S503, S504, and S505, with respect to the present number  $n$ , when the maximum value  $c_{\max}$  of the coefficients in the subject block T is as follows,

20

$$|c_{\max}| \geq Th \quad (8)$$

it is determined that there are significant conversion coefficients in the subject block T. The processing routine advances to step S506.

25 When the equation (8) is not satisfied, step S503 follows and bit data "0" indicating that no significant conversion coefficient exists in the subject block T is

generated.

In steps S504 and S505, the threshold value  $Th$  is set to  $Th/2$  and the value of  $n$  is reduced by "1" (height of bit plane which is used as a threshold value is reduced by "1"). After that, the processing routine  
5 is returned to step S501.

In step S506, bit data "1" showing that the significant conversion coefficients exist in the subject block  $T$  is generated.

10 In step S507, whether a size of present subject block  $T$  is equal to or less than a predetermined size (two pixels in both of the vertical and lateral directions in the embodiment) or not is discriminated. As a result of the discrimination, when the size of  
15 subject block  $T$  is equal to or less than the predetermined size, step S508 follows. When it is larger than the predetermined size, step S509 follows.

In step S508, bit data within a range from the  $n$ th bit plane to the  $n_{min}$ th bit plane corresponding to all  
20 of the coefficients (four coefficients in case of the embodiment) in the subject block  $T$  and sign bits of the coefficients are generated.

In step S509, the subject block  $T$  is further divided into four subject blocks  $T_m$  of a small size.  
25 Processes in step S500 and subsequent steps are repeated with respect to each of the subject blocks  $T_m$ .

The above procedure will now be described with



regard to specific examples. Fig. 5A shows the subject block T (each subband in Fig. 4B) which is first defined. The subject block T in this case is constructed by  $(8 \times 8)$  conversion coefficients.

5       As for the significant conversion coefficients, one (a value is "40") significant conversion coefficient shown by a hatched region exists in the subject block T and has the maximum value in the block. The other conversion coefficients are not significant  
10       and their values are equal to "0".

      When the process to sequentially divide the subject block T into the subject blocks  $T_n$  is executed in accordance with the procedure of Fig. 5E, it is divided in accordance with the order of Fig. 5A → Fig.  
15       5B → Fig. 5C, so that a bit data string as shown in Fig. 5D is outputted.

      The above process relates to the case where  $n = 5$  and  $n_{\min} = 3$ .

      By executing the above process, a bit data string  
20       as shown in Fig. 5D such that the position and value of each coefficient can be expressed can be outputted from the block comprising a plurality of multivalued coefficients. Arrows (1), (2), and (3) shown in Fig. 5D indicate the order by which the bit data is  
25       generated by the process and the order in which it is outputted to the post stage. The bits are outputted in accordance with the order of the arrows (1) → (2) →

(3).

The above processes will now be described in detail hereinbelow.

At the time point of Fig. 5A, a check is first  
5 made to see whether there is a coefficient in which the  
significant bit exists on the bit plane of the fifth  
bit or not. In this instance, it will be understood  
that only one such coefficient (significant  
coefficient) exists.

10 Subsequently, since the position of the  
significant coefficient is not specified in the state  
of Fig. 5A, the subject block T is divided into four  
blocks as shown in step S509. Thus, subject blocks of  
T0 to T3 shown in Fig. 5B are decoded. At this time,  
15 bit data "1" showing that the subject block T was  
divided into four blocks is outputted.

Similar processes are executed with respect to  
each of the subject blocks T0 to T3. That is, the  
processes in step S500 and subsequent steps are also  
20 executed for the blocks T0 to T3.

Although the above processes are first executed  
with respect to the subject block T0, after the  
presence of the significant coefficients was decided in  
step S502, the subject block is further divided into  
25 four blocks T00 to T03. At this time, bit data "1"  
showing that the subject block T0 was divided into four  
blocks is generated.

Since the block T0 is further divided into four blocks, the processes from step S500 are executed with respect to each of the blocks T00 to T03 prior to processing the blocks T1 to T3.

5           When the above processes are executed with respect to the subject block T00, since a size of subject block T00 is equal to  $(2 \times 2)$  pixels in step S507, the processing routine advances to step S508. Therefore, as for the block T00, the data of the fifth to third  
10       bits corresponding to each coefficient in the block, namely, 3-bit data "000", "000", "000", and "101" showing the presence or absence of the significant coefficient and 1-bit data "0", "0", "0", and "0" showing the positive or negative sign of each  
15       coefficient are sequentially outputted in accordance with the order shown in the drawing. The above procedure corresponds to the arrow (1).

          The processes for T00 are finished as mentioned above. Subsequently, processes for T01 are executed.  
20       No significant coefficient exists in the third to fifth bits in each conversion coefficient in T01. Therefore, by repetitively executing the processes in steps S502 and S503 to S505 to  $n = 3, 4, \text{ and } 5$ , "0" indicative of "the absence of the significant coefficient" is  
25       generated until the number  $n$  is less than 3. Subsequently, processes for T02 and T03 are similarly executed, so that "000", "000", and "000" are

outputted. The above procedure corresponds to the arrow (2).

Since the processes for T0 (T00 to T03) are finished as mentioned above, T1 to T3 are subsequently  
5 processed. Since no significant coefficient exists in the third to fifth bits in any one of the conversion coefficients in T1 to T3, "000", "000", "000" are outputted in a manner similar to T01 to T04. The procedure corresponds to the arrow (3).

10 The bit data outputted by the above processes is supplied to the entropy encoding unit 5 at the post stage.

Encoding process as a binary image

Explanation will now be made with respect to the  
15 case where the multivalued image data which is inputted should be expressed as a binary image by the discrimination unit 1, namely, it should be processed as binary image data (case where the prediction conversion unit 3 is made operative).

20 When it is decided that the multivalued image data which is inputted should be expressed as a binary image, the multivalued image data is outputted to the prediction conversion unit 3 by the switching unit 6. The prediction conversion unit 3 converts the  
25 multivalued image data which is inputted on a pixel unit basis as a binary image into prediction error data.

Figs. 6A and 6B are conceptual diagrams for

explaining the operation of the prediction conversion unit 3. In Figs. 6A and 6B, when the multivalue image data  $x$  is inputted on a pixel unit basis from the switching unit 6, a binarization unit 300 converts it  
5 into binary image data  $x_1$  of every pixel and outputs.

A pattern checking unit 301 extracts peripheral pixels (10 pixels shown in Fig. 6B, which will be explained hereinlater) of the pixel shown by  $x_1$  (referred to as an encoding subject pixel). At the  
10 same time, a template 302 in which all of possible combinations of the peripheral pixels and information (corresponding to a status  $S(i)$ , which will be explained hereinlater) showing the combinations are stored is referred.

15 Thus, the status  $S(i)$  corresponding to the extracted actual peripheral pixels is decided and outputted to the post stage. The status  $S(i)$  is used for generation of a prediction value when encoding the inputted encoding subject pixel.

20 Fig. 6B shows a positional relation between the present encoding subject pixel  $x_1$  to be encoded and the peripheral pixels which are extracted to generate the status  $S(i)$ . In the diagram,  $a_0$  to  $a_9$  denote pixels which have already been encoded.

25 The status  $S(i)$  will now be specifically explained. Since the binary image data  $x_1$  which is inputted is image data of one bit of each pixel, each

pixel value has either 0 or 1. Therefore, the number of combinations of the possible values of the peripheral pixels  $a_0$  to  $a_9$  of the encoding subject pixel is equal to 1024.

5           This state is the status  $S(i)$  showing a situation of the pixel values of the peripheral pixels of the actual encoding subject pixel. "i" denotes that the status corresponds to the  $i$ th combination among the 1024 combinations.

10           In the embodiment, since the binary image data  $x_1$  is inputted to the pattern checking unit 301 by completing in the block of  $(H_b \times W_b)$  pixels, in the encoding subject pixels existing at the left edge, upper edge, and right edge of the block, there is a  
15           case where the above 10 peripheral pixels do not exist. In the embodiment, in order to cope with such a situation, the processes are performed on the assumption that "0" exists in the peripheral pixels which do not actually exist.

20           The status  $S(i)$  is inputted to a prediction unit 303. The prediction unit 303 outputs any one of prediction values  $x_2$  stored in correspondence to each inputted status  $S(i)$  to a comparison unit 304. That is, the prediction unit 303 is a look-up table. The  
25           prediction value  $x_2$  corresponding to each status  $S(i)$  is the optimum value obtained by previously analyzing a binary sample image.

The binary image data  $x_1$  is also inputted to the comparison unit 304. That is, the data  $x_1$  of a certain encoding subject pixel and the prediction value  $x_2$  obtained by predicting the encoding subject pixel on the basis of the 10 peripheral pixels are simultaneously inputted to the comparison unit 304.

The comparison unit 304 compares the data  $x_1$  of the encoding subject pixel with the prediction value  $x_2$ , generates "0" as a prediction error  $e$  when they coincide, and generates "1" as a prediction error  $e$  when they do not coincide. The above processes are sequentially executed for the data  $x_1(x)$  of all of the pixels which are inputted.

Since the block division unit 7 executes the switching and output of the image data on a block unit basis of a predetermined size to the discrete wavelet conversion unit 2 or prediction conversion unit 3, the process of the prediction conversion unit 3 is completed every predetermined size of  $(Hb \times Wb)$ .

Therefore, by constructing the prediction error  $e$  outputted every block of each predetermined size so as to have a relation similar to the actual position of each encoding subject pixel, a map  $E$  of a size  $(Hb \times Wb)$  is constructed.

The map  $E$  obtained by the prediction conversion unit 3 is subsequently outputted to the area dividing unit 4. The area dividing unit 4 handles the map  $E$  in

a manner similar to the subbands outputted from the discrete wavelet conversion unit 2, so that the map E is processed by using almost similar processing steps. The area dividing unit 4 outputs division information showing a division result when the map E is divided and the actual prediction error values and positive/negative signs of the conversion coefficients as bit data.

Different from the conversion coefficients in the subband outputted from the discrete wavelet conversion unit 2, the prediction error value in the map E is limited to 0 or 1. Therefore, on the basis of a result of the discrimination which is inputted from the discrimination unit 1, namely, on the basis of information showing whether the inputted conversion coefficients construct the subband which is generated from the discrete wavelet conversion unit 2 or construct the map E which is generated from the prediction conversion unit 3, the area dividing unit 4 switches the area dividing process and a outputting method of the bit data string.

Specifically speaking, as for the conversion coefficients, for the case where the subband inputted from the discrete wavelet conversion unit 2 is divided into areas and the bit data string as shown in Fig. 5D is outputted, in the case where the map E inputted from the prediction conversion unit 3 is divided into areas



(1) At the time of initialization, the dividing subject area T is set to the whole map E and

5

(2) The block comprising the multivalue conversion coefficients is not divided but it is sufficient to merely divide the block comprising the 1-bit prediction error coefficients. Therefore, data indicative of one bit of the prediction error is outputted in place of outputting three bits indicative of the presence or absence of the significant coefficients and one bit showing the positive/negative sign as shown in Fig. 5D. For example, now assuming that T shown in Fig. 5A indicates the map E (a hatched area c3 indicates the prediction error value "1" and the other areas show "0"), bit data strings which are outputted are as follows in Fig. 5D.

25

The construction except for the above two points is fundamentally similar to that in case of area dividing the multivalued conversion coefficients and its description is omitted.

5       The bit data string outputted as mentioned above is encoded by the entropy encoding unit 5 and is outputted as final encoded data.

#### Data format

10       Figs. 7A to 7F show conceptual diagrams of a data format of encoded data which is generated by the encoding as a multivalued image or the encoding as a binary image described above.

15       Fig. 7A shows a whole construction of the encoded data which is finally outputted by the image processing apparatus of the embodiment. The encoded data is constructed by header information and a code stream.

20       As shown in Fig. 7B, the header information is constructed by: geometry information including the size of encoded image, the block size ( $H_b \times W_b$ ) obtained by dividing the image, and other information which is necessary upon decoding; and a level number of the discrete wavelet conversion (DWT).

25       As shown in Fig. 7C, a code stream is constructed by setting the divided block ( $H_b \times W_b$ ) to one unit. A block header is included in one unit.

A flag indicating whether the relevant block has been encoded as a multivalued image or encoded as a

binary image is included in the block header.

Further, in the case where the block is encoded as a multivalued image, the number  $n_{\max}$  of the highest bit plane in which the significant coefficient exists among the multivalued bits showing each conversion coefficient in the block is included in the block header. That is, the value  $n_{\max}$  can be also different every block that is encoded as a multivalued image. In the embodiment,  $n_{\min}$  is common to each block to be encoded as a multivalued image. However, by constructing such that the information of  $n_{\min}$  is also included in the encoded data in a manner similar to  $n_{\max}$ ,  $n_{\min}$  can be changed every block to be encoded as a multivalued image. In the case where the block is encoded as a binary image, the information of  $n_{\max}$  and  $n_{\min}$  is unnecessary.

Figs. 7D and 7F show constructions of code streams corresponding to each block divided by the block division unit 7.

Fig. 7D shows a construction of the code stream in the case where the block is encoded as a multivalued image. The code stream is further constructed every subband of the discrete wavelet conversion.

Fig. 7E shows a data format corresponding to one subblock among the subblocks shown in Fig. 7D. Each subblock has a similar data format. LL to HH1 denote the same denominations as those of the subbands shown in Fig. 4B.

According to the contents in Fig. 7E, two kinds of bit streams of a division bit and a coefficient bit alternately appear as shown in the diagram. The division bit is a bit which is outputted in steps S503 and S506 in the flowchart of Fig. 5E and the  
5 coefficient bit is a bit which is outputted in step S508.

Fig. 7F shows a construction of the code stream in the case where the block is encoded as a binary image.  
10 The code stream has a format such that the division bit and a prediction error bit are alternately arranged.

#### Decoding process

A method of decoding the encoded data formed by the encoding method of the embodiment will now be  
15 described.

Fig. 8 is a block diagram showing a decoding apparatus for decoding the encoded data formed by the encoding method of the embodiment. Explanation will now be made in detail hereinbelow with reference to  
20 Fig. 8.

The encoded data inputted through a transmission path or an accumulating media is decoded by an entropy decoding unit 13. In a header information analyzing unit 8, necessary information such as size of original  
25 image, size of block, and the like is read out and stored as information necessary for decoding.

The block header (refer to Fig. 7C) in the encoded

data is read out and whether the blocks which are sequentially read out have been encoded as multivalued images or encoded as binary images is discriminated. A discrimination result is outputted to the switching unit 6. Further, for the block encoded as a multivalued image,  $n_{\max}$  is read and stored.

The code streams (refer to Figs. 7C to 7F) read out on a block unit basis are inputted to an area dividing unit 9. The area dividing unit 9 is used to decode data (the subblock comprising the conversion coefficients or the map E) just before it is inputted to the area dividing unit 4 in Fig. 1 from the division bit and coefficient bit by which the relevant block is divided upon encoding or the prediction error bit.

The operation of the area dividing unit 9 in the case where a certain block shown by the encoded data that is inputted has been encoded as a multivalued image will now be described hereinbelow with reference to a flowchart of Fig. 9F. In the embodiment, it is assumed that the order when a plurality of subbands are encoded (area divided) on the encoding side has been predetermined.

First, the area of the relevant subband is assured from the code stream corresponding to a certain subband. The area corresponding to the size of this subband is set to an initial value of the subject block T. All of the coefficients in the area are initialized

to 0. The value of  $n_{\max}$  which is derived from the block header is set to an initial value of the subject bit plane  $n$ .

Subsequently, in step S900, when the value of  $n$  is  
5 less than the predetermined minimum bit plane number  $n_{\min}$ , the processes of the subject block  $T$  are finished.

In step S901, one division bit is read out from the code stream.

In steps S902 and S903, the value of the read  
10 division bit is checked. When it is equal to 0, 1 is subtracted from  $n$  and the processing routine is returned to step S900.

In steps S904 and S905, when the size of present subject block  $T$  is equal to or less than a  
15 predetermined size, for example, the size of 2 pixels in the vertical and lateral directions, the coefficient bit is read out from the code stream and all of the coefficients in the area are decoded.

In step S906, the present subject block  $T$  is  
20 divided into four small areas  $T_m$  and the same processes as those in the processes in step S900 and subsequent steps are sequentially executed with respect to each of the small areas.

The above procedure will now be described in  
25 detail with respect to specific examples. Figs. 9A to 9E show decoding states of the subject block  $T$  and code streams (bit data strings) regarding the subject block

T which are sequentially inputted.

Arrows (1)', (2)', and (3)' shown in Fig. 9E indicate the orders in which the bit data strings are actually inputted every bit in accordance with the  
5 order of (1)', (2)', and (3)'.

In the initial state, as shown in Fig. 9A, all of the subject blocks T have been initialized to 0 and are not divided. In step S901, the division information "1" of first one bit of the arrow (1)' is inputted.  
10 Thus, it is recognized that the subject block T includes the significant coefficient with respect to the present bit plane n. In step S906, the block T is divided into four small blocks T0 to T3. This procedure is shown as a state of Fig. 9B.

15 A decoding process of T0 will now be executed. First, since the second bit (division bit "1") of the arrow (1)' is inputted in step S901, it is possible to decide that there is the significant pixel in the conversion coefficients in T0. Therefore, the block T0  
20 is further divided into four small blocks T00 to T03 (refer to Fig. 9C).

Since the first small block T0 is further divided into small blocks here, the decoding process of T00 to T03 is preferentially executed.

25 First, with respect to the block T00, the processes are executed from step S900. In step S901, the division bit shown in the third bit (division bit

"1") of the arrow (1)' is inputted and it is possible to decide that the significant conversion coefficient exists in T00. However, since the size of T00 corresponds to the size of two pixels in the vertical and lateral directions, T00 is not further divided.  
5 The processing routine advances to step S905 and the remaining bit data strings of the arrow (1)' are inputted.

Now, since  $n_{\max} = 5$  has been known from the information included in the encoded data and the value of  $n_{\min}$  has also previously been known, by which number of bits each conversion coefficient is expressed can be decided. Therefore, first three bits in the bit data strings which are inputted are inputted as values  
10 showing the third to fifth bits of c0 and subsequent one bit is inputted as a positive/negative sign of the conversion coefficient. By this method, a conversion coefficient "40" of c0 is decoded. Similarly, with regard to c1 to c3 as well, the data is inputted and  
15 the conversion coefficient "0" is decoded (refer to Fig. 9D).  
20

Since the block T00 has been decoded as mentioned above, it will be understood that the bit data strings which are subsequently inputted by the arrow (2)' are  
25 used for decoding from T01.

Since the first three bits which are inputted for decoding the block T01 are equal to "000", it will be



understood that the conversion coefficient in which "1" exists at the fifth to third bits of T01 does not exist. Therefore, the conversion coefficients in the block T01 are decoded as 0. Similarly, T02 and T03 are  
5 also processed and the conversion coefficient 0 is decoded in the block.

Further, T1 to T3 are also decoded from the bit data string of the arrow (3)' and the conversion coefficient "0" is decoded in the block.

10 The above operations are also similarly executed even in case of decoding the map E encoded as a binary image. In this case, however, the above operations differ from in that the initial value of T is set for the whole block and that  $n_{\max}$  is initialized to 0 in a  
15 manner similar to the case of encoding and the bit of the positive/negative sign is not included. The details of the decoding process are omitted because it is sufficient to merely perform the process opposite to the encoding process.

20 The decoded conversion coefficient corresponding to each block as mentioned above is outputted to the switching unit 6.

On the basis of information showing whether the decoded conversion coefficient which is inputted from  
25 the header information analyzing unit 8 has been encoded as a multivalued image or encoded as a binary image, the switching unit 6 in Fig. 8 outputs the block

of the decoded conversion coefficient to an inverse discrete wavelet conversion unit 10 or an inverse prediction conversion unit 11.

5 A case where the decoded conversion coefficient has been encoded as a multivalued image will now be described hereinbelow.

10 The inverse discrete wavelet conversion unit 10 combines the subbands which were decoded and inputted to the original block construction shown in Fig. 4B and inversely converts to the value before the filtering process is executed in Fig. 4A. Although the inverse conversion is realized by repetitively performing the up-sampling and the filtering processes of the low pass filter and the high pass filter, the filter coefficients in this instance satisfy the reconstructing condition for those used upon encoding. For example, for the filters shown in the equations (4) and (5), the image data string  $x$  is calculated from

$$x(2n) = r(n) + \langle\langle(p(n)+1)/2\rangle\rangle \quad (10)$$

20 
$$x(2n+1) = r(n) - \langle\langle(p(n))/2\rangle\rangle \quad (11)$$

where,  $\langle\langle X \rangle\rangle$ : the maximum integer which does not exceed  $X$

by assuming that

$$p(n) = d(n-1) - \langle\langle(-r(n-1) + r(n+1))/4\rangle\rangle \quad (12)$$

25 Thus, the conversion coefficients in the block are inversely converted to the multivalued image data and are sequentially outputted to a block synthesizing unit

12.

On the other hand, the case where the decoded conversion coefficient has been encoded as a binary image will now be described.

5        In this case, each decoded conversion coefficient comprising one bit is inputted as a prediction error map E. The inverse prediction conversion unit 11 sequentially inputs the prediction errors  $e$  constructing the map E and decodes the pixel values by  
10        using the same template as that shown in Figs. 6A and 6B and the pixel values which have already been decoded. The detailed description are omitted here since it is sufficient to merely perform the process opposite to the foregoing encoding process. The  
15        decoded binary image is converted into the multivalued image and becomes multivalued image data.

      The block synthesizing unit 12 synthesizes the block of the multivalued image data which is inputted from the inverse discrete wavelet conversion unit 10  
20        and the block of the multivalued image data which is inputted from the inverse prediction conversion unit 11, thereby decoding the original image data and outputting it.

      According to the above embodiment, in the case  
25        where the area to be encoded as a multivalued image and the area to be encoded as binary image data mixedly exist in the image shown by the multivalued image data

that is inputted, the data can be efficiently encoded. That is, a redundancy of a space area which the original image has is removed, thereby spatially deviating the data. The conversion coefficients which  
5 are derived by the discrete wavelet conversion as a multivalued image and the prediction conversion as a binary image can be concentrated to the positions which are spatially deviated. Therefore, the subsequent area dividing unit 4 can divide the conversion coefficients  
10 into the partial significant coefficients and the other many insignificant coefficients. Thus, an amount of bit data which is outputted from the area dividing unit 4 can be reduced.

Although the above embodiment has been described  
15 on the assumption that a resolution of the image which is decoded from the final encoded data is the same as that of the original image, it is also possible to perform what is called a progressive encoding such that upon decoding, the original image is first decoded at a  
20 low resolution and, subsequently, it can be decoded at a high resolution.

In the following second embodiment, a case of constructing the first embodiment so that the progressive encoding can be performed will now be  
25 described.

Even in the second embodiment as well, a fundamental construction is similar to that of the

first embodiment and the encoding is executed by using the construction of Fig. 1. The detailed description of each unit, therefore, is omitted here.

5       The second embodiment differs from the first embodiment in a constructing method and a transmitting order of the encoded data (bit data string).

Fig. 10 shows a construction of the bit data string corresponding to each subband in case of encoding as a multivalued image.

10       A block (a-1) in Fig. 10 shows 16 blocks (blocks of  $(W_b \times H_b)$  surrounded by broken lines) divided by the block division unit 7. Each of the hatched blocks is a block which is encoded as a binary image and the remaining blocks are blocks which are encoded as  
15       multivalued images. The block (a-1) shows a state after it was already discrete wavelet converted. That is, the smallest block in each  $(W_b \times H_b)$  block corresponds to the subband LL.

20       In the first embodiment, as shown in Fig. 7D, the subbands LL to HH1 in one block are combined to one block. In the embodiment, however, the subbands are combined on a unit basis of each level "LL, HL3, LH3, HH3" (assumes level 3), "HL2, LH2, HH2" (assumes level 2), and "HL1, LH1, HH1" (assumes level 1) after the  
25       discrete wavelet conversion. For example, in the block (a-1), by performing an area dividing operation P, the bit data string in which only the subbands at the

discrete wavelet conversion level 3 were encoded is extracted and outputted (a-2).

5 The decoding side which inputs the bit data string at level 3 performs an area dividing operation  $P^{-1}$  at the time of decoding to each bit data string, decodes the coefficients, combines them to one, and constructs an area in which only the coefficients at level 3 of the discrete wavelet conversion are collected (a-3). By performing the inverse discrete wavelet conversion  
10 every block, an image obtained by reducing the original image into 1/4 in the vertical and lateral directions can be decoded.

Subsequently, on the encoding side, as shown in (b-1), by performing the area dividing operation  $P$ , the  
15 bit data string in which only the subbands at level 2 were encoded is extracted and outputted (b-2). The decoding side which inputs the bit data string at level 2 constructs an area of the conversion coefficients as shown in (b-3). Since the data at conversion level 3  
20 has already been decoded like (a-4), it is used together with each block comprising level 2 and the inverse discrete wavelet conversion is performed. Thus, an image having the resolution or size that is twice as large as that of the image decoded in (a-4)  
25 can be decoded (b-4).

Subsequently, on the encoding side, the bit data string in which only the subbands at level 1 were

encoded is outputted. On the decoding side as well, by executing processes similar to those mentioned above, an image having the same resolution or size as that of the original image can be finally decoded.

5           Although the case of encoding as a multivalued image has been described above, a case of encoding as a binary image can be also progressively encoded.

          Figs. 11A to 11C are diagrams for explaining the above method.

10           Fig. 11A shows the map E comprising the prediction error outputted from the prediction conversion unit 3. A result obtained by converting the map E to the bit data string by the area dividing unit 4 is shown in Fig. 11C. Fig. 11B shows a change in which the initial  
15           subject block T is divided.

          In Figs. 11A and 11B, a portion where the prediction error is equal to 1 is shown by a black area. A bit data forming method for performing the progressive encoding will now be described hereinbelow.

20           The subject block T in the initial state is constructed by  $(8 \times 8)$  pixels. Whether the significant conversion coefficient (prediction error "1") exists in the block T or not is discriminated in step S502 in Fig. 5E. When it is decided that there is the  
25           significant conversion coefficient, bit "1" showing that the block T is further divided is outputted. In this state, since the position where the significant

conversion coefficient exists in T cannot be determined, it is also possible to consider that all of the prediction errors in T are equal to "1" at this time point. This state is shown by D0(T) at the leftmost position in Fig. 11B.

5       The size of T is checked in step S507. The area division is performed in step S509 and T is divided into T0 to T3. Further, with respect to the blocks T0 to T3, the processes described in the first embodiment are executed and the blocks (T0 and T3 in this case) which were decided to be significant are further divided into small blocks. By recursively performing the above dividing process, a state of D3 in Figs. 11B and 11C, namely, the bit data string to decode the resolution or size of the original image can be formed.

10       In the embodiment, different from the processes shown in the flowchart of Fig. 5E, the bit data is not actually outputted in steps S506 and S503. In place of it, a tree structure of the bits as shown in Fig. 11C is formed. In Fig. 11C, although there is no branch in the portion written as a prediction error, this is because since the area reached the minimum size, the division is not performed and the bit data itself of the prediction error is formed.

20       The output from the area dividing unit 4 to the entropy encoding unit 5 is performed by using a node of a predetermined depth in the tree structure as a unit,



namely, by using the portion surrounded by a frame in Fig. 11C as each unit. Now, assuming that those portions are labelled as D1 to D3, a structure of the bit data string which is formed is as shown in Figs.

5 12A to 12D.

Fig. 12B shows a state when D0 corresponding to each block divided by the block division unit 7 is first outputted to the decoding side. By decoding only D0, a map E as shown in the diagram is formed. Each of  
10 the blocks surrounded by broken lines shown here corresponds to each block divided by the block division unit 7.

In case of decoding only D0, each block surrounded by the broken lines can express only either black or  
15 white and an image of a very low resolution is decoded.

Subsequently, D1 is outputted from the encoding side. On the decoding side, an image as shown in Fig. 12C can be decoded on the decoding side from both of D1 and D0 which was first inputted.

20 Similarly, by sequentially inputting D2 and D3, the decoded image sequentially changes from the low resolution to the high resolution and the original image as shown in Fig. 12D can be finally decoded.

As mentioned above, according to the second  
25 embodiment, not only the effect of the first embodiment can be obtained but also the progressive encoding such that the decoded image on the decoding side is

sequentially changed from the low resolution to the high resolution can be executed. Even if there is only small encoded data on the decoding side, the outline of the original image can be grasped.

5           The invention can be applied to not only the case of switching the binary value and multivalue and encoding but also the case of switching N values and M values and encoding.

10           Not only the case of automatically discriminating the image data by the discrimination unit 1 in Fig. 1 but also the case of manually switching the switching unit 6 is included in the invention.

15           The invention can be applied to a system in which each unit necessary for the encoding and decoding processes is connected and used or can be also applied as one equipment.

          A third embodiment of the invention will now be described hereinbelow with reference to the drawings.

20           Fig. 13 shows an image processing apparatus to execute the third embodiment of the invention. In the diagram, reference numeral 101 denotes an image input unit; 102 a frame memory to store the whole image (picture plane) to be encoded; 103 a block dividing circuit; and 104 an arithmetic encoding circuit.

25           In the embodiment, what is called a binary image such that "0" assumes a pixel value of a background and "1" assumes a pixel value of a foreground is encoded.

The operation of each unit in the embodiment will now be described in detail hereinbelow.

First, all of the pixel data (1 or 0) showing the image (corresponding to one picture plane) as an  
5 encoding target is sequentially inputted from an image input unit in accordance with the raster scanning order and is stored into the frame memory 102.

The image input unit is, for example, an image pickup apparatus such as scanner, digital camera, or  
10 the like, an interface of a network line, or the like.

The block dividing circuit 103 divides the image of one picture plane comprising the pixel data stored in the frame memory 102 into a plurality of blocks by using a characteristic block dividing method such that  
15 blocks of different sizes mixedly exist.

The block dividing method will now be described in detail hereinbelow with reference to the drawings.

According to the block division, an image of one picture plane to be encoded is extracted every block  
20 (explained as  $(4 \times 4)$  pixels in the embodiment) of a predetermined size and this block is further recursively divided into four blocks on the basis of a pixel distribution, thereby forming small blocks.

By the bit data string obtained after completion  
25 of the dividing process, a reversible encoding such that the arrangement of the background pixels and the foreground pixels can be perfectly expressed can be

realized.

A procedure of the dividing process will be first explained.

Fig. 14 is a flowchart showing a flow of processes  
5 of the block dividing circuit 103.

First in step 201, the image of one picture plane  
stored in the frame memory 102 is read out on a block  
unit basis. That is, prior to performing the block  
division, while the image is previously divided into  
10 blocks of a predetermined size ( $4 \times 4$  pixels) by a  
block dividing circuit at the post stage, the image  
data is sequentially read out. The block dividing  
circuit 103 further performs the block division every  
read-out block of ( $4 \times 4$ ) pixels.

15 Fig. 15A shows a state of a certain block among  
the blocks of ( $4 \times 4$ ) pixels which are sequentially  
read out. This certain block is referred to as a  
subject block hereinafter and explanation will be made  
by using the subject block.

20 First in step 201, a check is made to see if all  
of the pixels in the subject block are set to  
background "0". That is, whether there is no  
foreground "1" in the subject block of ( $4 \times 4$ ) pixels  
or not is discriminated.

25 Thus, if all of the pixels are equal to "0", step  
202 follows. When any one of the pixels is equal to  
"1", step 203 follows.

In step 202, bit "0" showing that the original block of  $(4 \times 4)$  pixels is not divided any more is outputted as an intermediate code and the dividing process of the subject block is finished.

5           On the other hand, in step 203, bit "1" showing that the block is divided is outputted as an intermediate code. In step 204, when a size of subject block is larger than the predetermined smallest size (the block of  $(2 \times 2)$  pixels is set to the minimum  
10       block in the embodiment), step 205 follows. If NO, step 206 follows.

The set size of minimum block can be manually changed.

In step 205, as shown in Fig. 20, the subject  
15       block is divided into four blocks b0 to b3 (in order to distinguish from the original block of  $(4 \times 4)$  pixels, these four blocks of  $(2 \times 2)$  pixels are called subblocks). With respect to each of the subblocks b0, b1, b2, and b3 formed here as well, the dividing  
20       process is executed in accordance with the procedure from step 201 in a manner similar to the foregoing block of  $(4 \times 4)$  pixels.

In step 206, the pixel values  $(2 \times 2)$  pixels in the embodiment) in the block are sequentially scanned and  
25       either "1" or "0" is outputted.

In Fig. 15A, a white pixel indicates a background pixel, namely, a pixel of a value "0" and a black pixel

shows a foreground pixel, namely, a pixel of a value "1". Specific dividing processes of the block dividing circuit 103 for the subject block will now be described hereinbelow.

5           First, as for the subject block (refer to Fig. 15A), since it is determined in step 201 that all of the pixels in the block are not equal to "0", "1" is outputted as an intermediate code showing the information of the block division (step 203). Since it  
10 is decided in step 204 that the size of subject block of  $(4 \times 4)$  pixels is larger than the size of  $(2 \times 2)$  pixels by comparing it with the minimum block size, the processing routine advances to step 205.

          In step 205, the subject block is divided into  
15 four subblocks b0, b1, b2, and b3 of  $(2 \times 2)$  pixels as shown in Fig. 15B. The block dividing processes from step 201 are further executed with respect to each of the subblocks b0, b1, b2, and b3.

          Since all of the pixel values in each of the  
20 subblocks b0, b1, and b2 are equal to "0", the processing routine advances to step 202 as a result of discrimination in step 201. The intermediate code "0" is outputted as information of division for each of the subblocks b0, b1, and b2. After that, the dividing  
25 processes of those three blocks are finished.

          On the other hand, as for the subblock b3, since all of the pixels in the block are not equal to "0",

"1" is outputted as an intermediate code showing the information of the block division (step 203). After that, since the size of subblock b3 is equal to the minimum block size of  $(2 \times 2)$  pixels in step 204, the processing routine advances to step 206. In step 206, the block is divided every pixel and four pixel values "0", "1", "1", and "1" in the block are also outputted as intermediate codes.

By executing the above dividing processes, a bit data string "100010111" as shown in Fig. 16 is outputted as an intermediate code corresponding to the subject block of  $(4 \times 4)$  pixels shown in Fig. 15A. It can be said that the first, second, third, fourth, and fifth bits of the bit data string are division information indicating whether the block has been divided or not.

When the subject block is decoded from the intermediate code on the decoding side, it is first known from first bit "1" that the subject block has been divided into the blocks of  $(2 \times 2)$  pixels and it is known from subsequent bits "0", "0", and "0" that all of the pixels of the first three subblocks b0 to b2 are equal to "0", so that they can be decoded. It is known from subsequent bit "1" that only the subblock b3 has been further divided. Since the subblock b3 is the minimum block, it is known that subsequent bits "0", "1", "1", and "1" are the actual pixel values. All of

the pixels are decoded.

The above intermediate code is a reversible code which certainly shows at which position in the subject block the significant pixel "1" exists and at which position "0" exists.

The intermediate code which is outputted from the block dividing circuit 103 is arithmetically encoded by the arithmetic encoding circuit 104. In the embodiment, QM-Coder is used as a method of arithmetic encoding.

When the QM-Coder is used, a procedure for adaptively encoding a binary symbol b of "1" or "0" generated in a certain status S in accordance with the status S has been described in detail in the International Standard ITU-T T.81 | ISO/IEC 10918-1 Recommendation or the like about a still image. Therefore, its description is omitted here. As a method of classifying the status S, a method of using statuses of peripheral pixels of a binary encoding pixel or the like is known.

According to the embodiment, however, the intermediate code indicative of the information of the block division is encoded instead of merely encoding the pixel values of the binary image and this method is a peculiar method different from the well-known method. Therefore, the classifying method of the status S will be described in detail.



In the binary intermediate code which is outputted from the block dividing circuit 103, the block division information (bit showing whether the block is further divided into subblocks or not) and the actual pixel values (last four bits "0", "1", "1", "1" in Fig. 16) in the block after completion of the dividing process mixedly exist. The arithmetic encoding circuit 104 classifies those two bits into different statuses and encodes. Particularly, as for the bit indicative of the block division information, the arithmetic encoding according to the detailed status S is executed in consideration of the block dividing situation of the peripheral blocks.

A case of arithmetically encoding the bit of the block division information as a feature of the invention will now be described in detail hereinbelow.

As described in the operation explanation of the block dividing circuit 103, the block division information shows whether a predetermined block is divided or not. If the blocks (refer to Fig. 15A) which are first sequentially read out are excluded, the blocks become the subblocks of the other blocks (blocks before the division). In the embodiment, the arithmetic encoding is efficiently executed in consideration of the above point.

Specifically speaking, in case of arithmetically encoding the block division information of the

subblock, the status  $S$  is classified in accordance with the position (the same position as that of any one of  $b_0$ ,  $b_1$ ,  $b_2$ , and  $b_3$ ) of the subblock and the number of divided subblocks among the other subblocks which are included in the original block before division and have already been divided (for example,  $b_0$  in case of the subblock  $b_1$ ;  $b_0$  and  $b_1$  in case of the subblock  $b_2$ ;  $b_0$  to  $b_2$  in case of the subblock  $b_3$ ; none in case of the subblock  $b_0$ ).

For example, when the block division information ("0" in the embodiment) of the subblock  $b_0$  is arithmetically encoded, the other subblocks which are included in the block (subject block in Fig. 15A in the embodiment) before it is divided into this subblock and have already been divided do not exist. Therefore, the block division information of the subblock  $b_0$  is arithmetically encoded as a status  $S(1)$ . A status  $S(n)$  indicates the  $n$ th status.

When the block division information ("0" in the embodiment) of the subblock  $b_1$  is arithmetically encoded, the other subblocks which are included in the block (subject block in Fig. 15A in the embodiment) before it is divided into this subblock and have already been divided are only one subblock  $b_0$ .

Therefore, the statuses can be classified into two statuses  $S(2)$  and  $S(3)$  indicating whether the subblock  $b_0$  has been divided or not (namely, whether the block

division information of b0 is equal to "1" or "0").

Thus, when the block division information of the subblock b2 is arithmetically encoded, the arithmetic encoding is executed on the basis of either one of the statuses S(2) and S(3).

When the block division information ("0" in the embodiment) of the subblock b2 is arithmetically encoded, the other subblocks which are included in the block (subject block in Fig. 15A in the embodiment)

before it is divided into this subblock and have already been divided are the two subblocks b0 and b1.

Therefore, the statuses can be classified into four statuses S(4) to S(7) showing whether the subblocks b0 and b1 have been divided or not (namely, whether the

block division information of b0 and b1 is equal to "1" or "0"). Consequently, when the block division information of the subblock b2 is arithmetically encoded, the arithmetic encoding is performed on the basis of any one of the statuses S(4) to S(7).

When the block division information ("1" in the embodiment) of the subblock b3 is arithmetically encoded, the other subblocks which are included in the block (subject block in Fig. 15A in the embodiment)

before it is divided into this subblock and have

already been divided are the four subblocks b0 to b3.

Therefore, the statuses can be classified into eight statuses S(8) to S(15) showing whether the subblocks b0

to b3 have been divided or not (namely, whether the block division information of b0 to b3 is equal to "1" or "0"). Consequently, when the block division information of the subblock b3 is arithmetically  
5 encoded, the arithmetic encoding is performed on the basis of any one of the statuses S(8) to S(15).

In the statuses S(1) to S(15) which were individually divided as mentioned above, the intermediate codes are sequentially arithmetically  
10 encoded by the QM-Coder. In the QM-Coder, an appearance probability of the next symbol is presumed from the encoded symbol string every status S and the encoding is executed in accordance with the appearance probability of the symbol in each status.

15 The encoding of the binary image data can be efficiently executed by the above processes.

Although the system of encoding the binary image data has been provided in the above third embodiment, the invention is not limited to it. That is, as for a  
20 point that the efficient arithmetic encoding is executed in consideration of the image dividing process, particularly, it is not always necessary to perform the encoding of the binary image data. The invention can be also applied to the case of encoding  
25 multivalue image data. Such a modification will now be described as a fourth embodiment of the invention hereinbelow.

Fig. 17 shows a block diagram of the fourth embodiment according to the invention. In the diagram, reference numeral 501 denotes an image input unit to input multivalued image data of one picture plane and  
5 502 indicates a frame memory to store the multivalued image data of one picture plane. In a manner similar to the third embodiment, the image input unit 501 is, for example, an image pickup apparatus such as scanner, digital camera, or the like, an interface such as a  
10 network line, or the like.

Reference numeral 503 denotes a discrete wavelet conversion circuit to discrete wavelet convert multivalued image data; 504 a subband extraction circuit to sequentially extract a plurality of subbands  
15 generated by the discrete wavelet conversion; 505 a block dividing circuit for performing a process similar to that of the block dividing circuit 103 in Fig. 1; and 506 an arithmetic encoding circuit.

In the embodiment, explanation will be made on the assumption that monochromatic multivalued image data of  
20 8 bits is encoded. However, the invention is not limited to such an example. A case where the invention is applied to a color multivalued image encoding such that 8-bit multivalued image data is encoded as a  
25 luminance L and 8-bit multivalued image data is encoded as chromaticities a and b is also incorporated. The invention is not limited to the image data but the

invention can be also applied to a case of encoding multivalued information showing the status of each pixel of an image area.

First, multivalued image data to be encoded is inputted from the image input unit 501 and stored into the frame memory 502. The discrete wavelet converting circuit 503 reads out the multivalued image data of one picture plane stored in the frame memory 502 every block of a predetermined size and sequentially executes the discrete wavelet conversion. By the discrete wavelet conversion, the original block is divided into a predetermined number of frequency bands (hereinafter, called subbands) as shown in Figs. 18A to 18C. The discrete wavelet conversion for image data string  $x(n)$  in the embodiment is executed by the following equations.

$$r(n) = \langle\langle (x(2n) + x(2n+1))/2 \rangle\rangle$$

$$d(n) = x(2n) - x(2n+1)$$

where,  $\langle\langle X \rangle\rangle$ : the maximum integer which does not exceed  $x$

$r(n)$ ,  $d(n)$ : conversion coefficients

$r(n)$ : low frequency component

$d(n)$ : high frequency component

Although the above conversion equations relate to one-dimensional data, by sequentially executing the conversion in the horizontal direction and the vertical direction, the original block can be divided into four

subbands of LL, HL, LH, and HH as shown in Fig. 18A.

Further, by again performing the discrete wavelet conversion to the LL component, the block is divided into seven subbands as shown in Fig. 18B. The number  
5 of times of execution of the two-dimensional discrete wavelet conversion is called a level number. It is assumed that each subband is expressed and specified as shown by LH3 (LH component at level 3) by adding the level number to LL, HL, LH, and HH showing the  
10 components. In the embodiment, the conversion at level 4 is performed and the block is divided into 13 subbands shown in Fig. 18C.

The subband extraction circuit 504 sequentially extracts only specific bands such as LL4, HL4, LH4,  
15 HH4, HL3, LH3, ..., HH1 from the conversion coefficient data divided into 13 subbands by the discrete wavelet conversion circuit 503 in accordance with the order from the low frequency band and outputs them to a quantization circuit 507 at the post stage.

20 In the quantization circuit 507, the values of all of the conversion coefficients in each of the subbands which are sequentially outputted by the subband extraction circuit 504 are divided by a predetermined quantization coefficient, thereby performing the  
25 quantization. In the embodiment, 2 is used as a quantization coefficient.

The block dividing circuit 505 recursively

executes the block dividing process similar to that in the third embodiment with reference to the values of the conversion coefficients in each subband quantized by the quantization circuit 507. This method will be explained hereinlater.

As a result of division mentioned above, the intermediate code is formed by outputting the information showing the block division and a value (positive/negative signs and the absolute value) of the conversion coefficient of the block whose size is equal to or smaller than the predetermined minimum size (assumes  $(2 \times 2)$  pixels in the embodiment).

The block dividing process in the embodiment will now be described.

In the block division of a binary value in the third embodiment, whether the block as a target is divided or not is determined on the basis of the presence or absence of the significant pixel "1" in the block. However, the deciding method is almost the same in terms of this point. Specifically speaking, whether the block is further divided into four subblocks or not is determined by checking whether a pixel of a certain predetermined density (bit plane of a predetermined height) or more exists in the block or not. In case of the block division of a binary value, when the size of subblock after the repetition of the division becomes the minimum size, the actual pixel values "1" and "0"



in the subblock are generated. In the embodiment, however, multivalued bit data is outputted. Explanation will now be made hereinbelow with reference to the drawings.

5           Fig. 19 shows a flow of dividing process of a multivalued block which is executed by the block dividing circuit 505. Processes of the block dividing circuit 505 will now be sequentially explained hereinbelow with reference to the diagram.

10           Prior to the block dividing process by the block dividing circuit 505, an initial value of the number  $n$  of the subject bit plane is set. It is assumed that the bit plane number is set to 0 for the LSB plane and increases one by one toward the MSB plane.

15           The initial value of the subject bit plane number  $n$  is set to the theoretical maximum bit number necessary to express an absolute value of the conversion coefficient in the subband inputted to the block dividing circuit 505. This number is determined  
20 by the number of bits per pixel of an image to be encoded, the number of bits after completion of the wavelet conversion, and further, the number of bits after the quantization.

          In case of the embodiment, the multivalued image to  
25 be encoded is expressed by 8 bits per pixel. The numbers of bits of the absolute values of the conversion coefficients which are derived by the

converting process of the discrete wavelet conversion circuit 503 differ depending on the components and are set to 8 bits for the LL, HL, and LH components and to 9 bits for the HH component.

5        Since the subband is further divided by the quantization coefficient 2 by the quantization circuit 507, the initial value of  $n$  is set to 7 bits for the LL, HL, and LH components and to 8 bits for the HH component.

10        The block dividing circuit 505 first sets the whole subbands extracted by the subband extraction circuit 504 to a processing target block (subject block). First in step 701, the maximum value  $C_{\max}$  of the absolute values of the coefficients in the subject  
15        block is obtained and is compared with a threshold value  $2^n - 1$  which is determined from the number  $n$  of subject bits. When  $C_{\max}$  is larger than the threshold value, step 705 follows. If NO, the processing routine is returned to step 702.

20        That is, this is equivalent to that the absolute values of the conversion coefficients in the processing subject block are natural binary expressed and divided into bit planes and whether all of the subject bit  
25        planes are equal to "0" or not is discriminated. In step 702, "0" showing that the block is not divided in the relevant bit plane is outputted as an intermediate code as information of the block division.

In step 703, the value of n is examined. When n is larger than 0, the processing routine advances to step 704. If NO, the processes about the subject block are finished. In step 704, the value of n is reduced  
5 by "1" and the processing routine is returned to step 701.

In step 705, the intermediate code "1" showing that the block has been divided is outputted as information of the block division. In step 706, the  
10 size of subject block is compared with the predetermined minimum block size. When the subject block size is larger than the minimum block size, step 707 follows. If NO, the processing routine advances to step 708.

15 In step 707, the subject block is divided into four subblocks and the initial value of the subject bit plane number is set to the present value of n with respect to each of the subblocks. The processes from step 701 are executed.

20 In step 708, the absolute values are natural binary expressed by n bits and are outputted from the upper bit one by one in accordance with the raster scanning order with regard to the coefficients in the subject block. If the coefficient value is not equal  
25 to "0", the positive/negative sign ("0" if "+"; "1" if "-") is also outputted.

By the above processes, each of the subbands

inputted to the block dividing circuit 505 is converted into the intermediate code and outputted.

5 The arithmetic encoding circuit 506 arithmetically encodes the intermediate codes which are outputted from the block dividing circuit 505 and outputs the final encoded data. In the embodiment as well, it is assumed that the arithmetic encoding is performed by using the QM-Coder in a manner similar to the third embodiment.

10 The details of the processing procedure of the QM-Coder are also omitted here in a manner similar to the third embodiment and only the classifying method of the status S which is used for arithmetic encoding will now be described. The block division information (bit showing whether the block is divided or not) and the  
15 multivalue conversion coefficient value (bits showing the absolute values and positive/negative sign) are included in the intermediate code which is outputted from the block dividing circuit 505. Those information is arithmetically encoded on the basis of the  
20 individual statuses S in a manner similar to the third embodiment.

Further, in the embodiment, when the bits to express the absolute values of the conversion coefficients are arithmetically encoded, the status is  
25 classified on the basis of the bit plane number to which the bit to be encoded belongs. The status about the block division information is also finely

classified. The block is arithmetically encoded in consideration of a fact that except for the subband as a first division target, the block becomes the subblocks of the other blocks (original block before  
5 division).

Specifically speaking, in case of arithmetically encoding the block division information of the subblock, the status  $S$  is classified in accordance with the position (the same position as that of any one of  
10  $b_0$ ,  $b_1$ ,  $b_2$ , and  $b_3$ ) of the subblock and the number of subblocks among the other subblocks which are included in the original block before the division and have already been divided (for example,  $b_0$  in case of the subblock  $b_1$ ;  $b_0$  and  $b_1$  in case of the subblock  $b_2$ ;  $b_0$   
15 to  $b_2$  in case of the subblock  $b_3$ ; and none in case of the subblock  $b_0$ ).

For example, when the block division information of the subblock  $b_0$  is arithmetically encoded, the other subblocks which are included in the block before it is  
20 divided into this subblock and have already been divided do not exist. Therefore, the block division information of the subblock  $b_0$  is arithmetically encoded as a status  $S(1)$ . The status  $S(n)$  indicates the  $n$ th status.

25 When the block division information of the subblock  $b_1$  is arithmetically encoded, the other subblocks which are included in the block before it is

divided into this subblock and have already been  
divided are one subblock b0. Therefore, the statuses  
can be classified into two statuses S(2) and S(3)  
showing whether the subblock b0 has been divided or not  
5 (namely, whether the block division information of b0  
is equal to "1" or "0"). Thus, when the block division  
information of the subblock b2 is arithmetically  
encoded, the arithmetic encoding is executed on the  
basis of either one of the statuses S(2) and S(3).

10 When the block division information of the  
subblock b2 is arithmetically encoded, the other  
subblocks which are included in the block before it is  
divided into this subblock and have already been  
divided are two subblocks b0 and b1. Therefore, the  
15 statuses can be classified into four statuses S(4) to  
S(7) showing whether the subblocks b0 and b1 have been  
divided or not (namely, whether the block division  
information of b0 and b1 is equal to "1" or "0").  
Thus, when the block division information of the  
20 subblock b2 is arithmetically encoded, the arithmetic  
encoding is executed on the basis of any one of the  
statuses S(4) to S(7).

When the block division information of the  
subblock b3 is arithmetically encoded, the other  
25 subblocks which are included in the block before it is  
divided into this subblock and have already been  
divided are four subblocks b0 to b3. Therefore, the

statuses can be classified into eight statuses S(8) to S(15) showing whether the subblocks b0 to b3 have been divided or not (namely, whether the block division information of b0 to b3 is equal to "1" or "0"). Thus, when the block division information of the subblock b3 is arithmetically encoded, the arithmetic encoding is executed on the basis of any one of the statuses S(8) to S(15).

In the statuses S(1) to S(15) which were individually classified as mentioned above, the intermediate codes are sequentially arithmetically encoded by the QM-Coder. In the QM-Coder, an appearance probability of the next symbol is presumed from the encoded symbol string every status S and the encoding is executed in accordance with the appearance probability of the symbol in each status.

By the above processes, the encoding of the multivalue image data can be efficiently executed.

The invention is not limited to the foregoing embodiments. For example, in the fourth embodiment, although the filter of two taps has been used in the discrete wavelet conversion, another filter of a larger number of taps can be also used. Although the QM-Coder has been used as an arithmetic encoding method, another arithmetic encoding such as Q-Coder, CJ-Coder, or the like can be also used.

The system for entropy encoding the intermediate

code is not limited to the arithmetic encoding. For example, a Huffman encoding such that the method is switched in accordance with the status or the like can be also used.

5           Although the third embodiment has been described on the assumption that an image of one picture plane to be encoded is a mere binary image, the invention is not limited to it. That is, the invention also incorporates a case where it is applied when position  
10   information of one picture plane showing the position "1" of a photograph area and the position "0" of a character/diagram area in one picture plane is encoded in place of encoding the binary image of one picture plane.

15           Although the fourth embodiment has been described on the assumption that the image of one picture plane to be encoded is a mere multivalued image, the invention is not limited to it. That is, the invention also incorporates a case where it is applied when multivalued  
20   identification information for each position in one picture plane is encoded in place of encoding the multiimage of one picture plane.

          The invention can be applied as a part of a system comprising a plurality of equipment (for example, a  
25   host computer, interface equipment, a reader, a printer, and the like) or can be also applied to a part of an apparatus comprising one equipment (for instance,



a copying apparatus, a facsimile apparatus).

The invention is not limited to an apparatus and a method for realizing the foregoing embodiments. A case where program codes of software to realize the  
5       embodiments are supplied to a computer (CPU or MPU) in the system or apparatus and the computer of the system or apparatus makes the above various devices operative in accordance with the program codes, thereby realizing the embodiments is also incorporated in the scope of  
10       the invention.

In this case, the program codes themselves of the software realize the functions of the embodiments. The program codes themselves and means for supplying the program codes to the computer, specifically speaking, a  
15       storing medium in which the program codes have been stored are also incorporated in the scope of the invention.

As such a storing medium to store the program codes, for example, it is possible to use a floppy  
20       disk, a hard disk, an optical disk, a magnetooptic disk, a CD-ROM, a magnetic tape, a non-volatile memory card, an ROM, or the like.

The program codes are incorporated in the scope of the invention in not only a case where the functions of  
25       the embodiments are realized by controlling the various devices by the computer in accordance with only the supplied program codes but also a case where the

embodiments are realized in cooperation with the OS (Operating System) by which the program codes operate on the computer, another application software, or the like.

5           Further, a case where the supplied program codes are stored into a memory provided for a function expansion board of a computer or a function expanding unit connected to the computer and, after that, a CPU or the like equipped for the function expansion board  
10           or function expanding unit executes a part or all of the actual processes on the basis of an instruction of the program codes and the embodiments are realized by those processes is also incorporated in the scope of the invention.

15           The present invention is not limited to the foregoing embodiments but many modifications and variations are possible within the spirit and scope of the appended claims of the invention.